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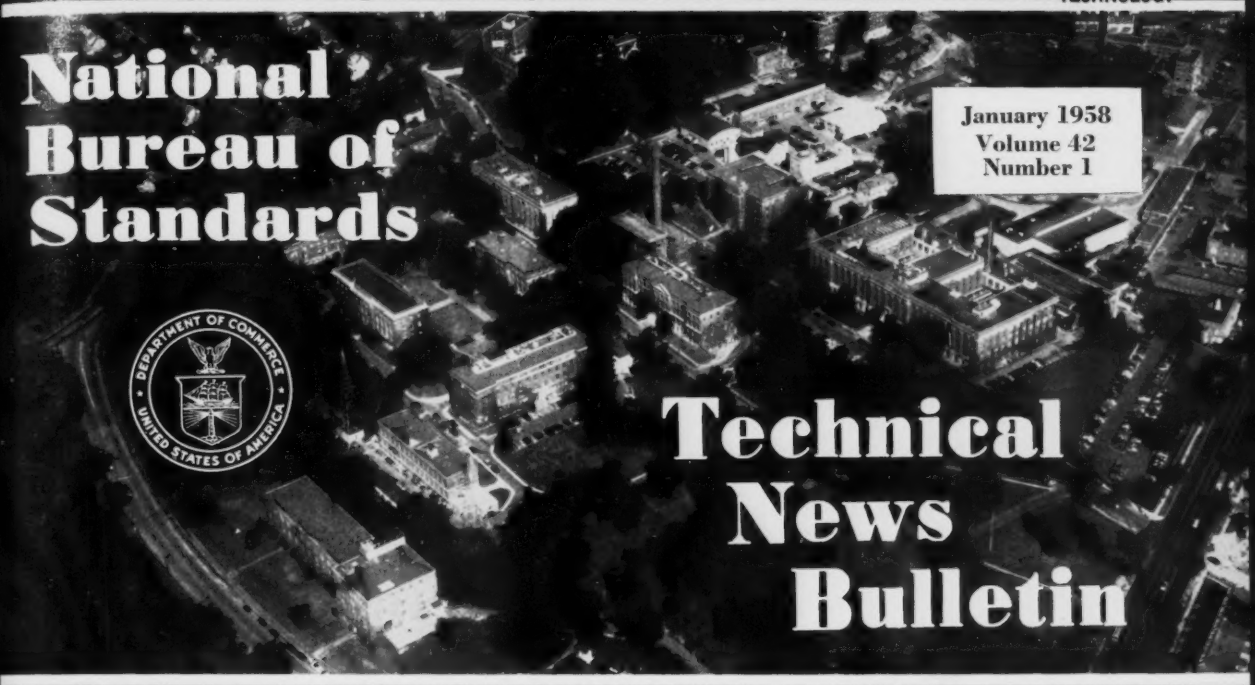

Technical News Bulletin

Absolute Calibration of a Capacitance-Type Vibration Pickup

FOR the past three years, condenser microphones have been successfully used in the absolute calibration of vibration amplitude detectors at the National Bureau of Standards.[1,2] In its most recent form, the calibration procedure is not only convenient to carry out, but can be done in about ½ hour when a good-quality laboratory microphone of known response and capacitance is available. All the required quantities can be determined with high precision—voltage ratios, length, barometric pressure, and capacitance.

At the same time, a capacitance-type vibration pickup has been designed which, besides being specially adapted to calibration in this way, has a number of other advantages: It can be made small, can be built in a variety of shapes for special purposes, and can operate as a probe at the end of a long cable. A model in use at the Bureau measures vibration amplitudes as small as 0.1 angstrom (about one-tenth the diameter of a hydrogen atom); it has been calibrated over the frequency range from 10 to 40,000 c/s. The dynamic range (ratio of largest to smallest amplitude) is about 10^5; the range of amplitudes can be shifted by modifying the pickup design.

The pickup and the associated calibration procedures were developed by W. Koidan of the sound laboratory. An outgrowth of proposals made 10 years ago by the sound laboratory to apply acoustic methods to vibration measurements, these results should be of interest to structural engineers concerned with the measurement and control of vibrations in various kinds of machinery. Manufacturers of high-speed aircraft and other forms of transportation, for example, are concerned with the effect of vibration not only on the structural stability of the vehicles but also on the comfort of the passengers. In a somewhat different type of application, the Bureau is now using the capacitance-type pickup to determine the displacement of a vibrating assembly (consisting of an electrically driven barium titanate tube and a force pickup) which is employed in measuring the mechanical impedance of the human head[3] and the threshold of hearing by bone conduction.

Capacitance-Type Pickup

The pickup is designed to operate in a low impedance bridge circuit, which results in a high signal-to-

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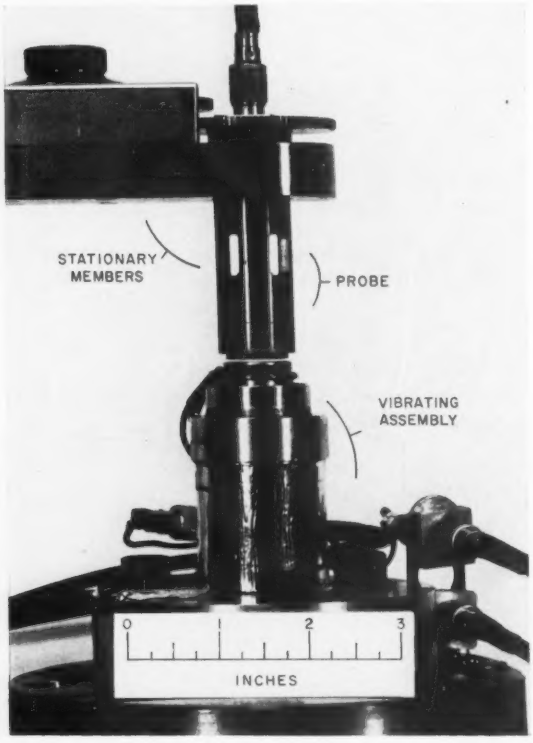
Summer Career Program Aids in Scientist Recruitment

noise ratio [2] and permits operation of the pickup at some distance from the electronic detecting circuit by way of a coaxial cable. Built in the form of a probe, the pickup is intended for measuring the vibration of flat metallic surfaces. The sensitive element is a metallic disk (pickup electrode) at the end of the probe; this serves as one plate of a condenser, the other plate being the vibrating surface. The probe also contains a small inductance and suitable shielding to fix the stray capacitance of the pickup electrode.

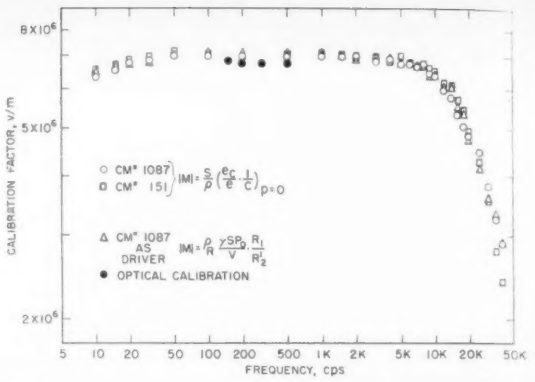
In use, the probe is supported rigidly at a small, predetermined distance from the vibrating surface, the distance being precisely adjustable by means of a null indicator. The change in capacitance between the stationary pickup and the moving surface modulates a high-frequency carrier signal; the latter is then detected to produce a voltage output corresponding to the motion.

Calibration Methods

For a given vibration detector, the ratio of the output voltage (e_c) to the amplitude of vibration (ξ) of the moving surface is called the "calibration factor."



The capacitance-type vibration pickup in use. The probe is held stationary at a predetermined distance from the vibrating assembly. The changing capacitance between the vibrating surface and the perforated electrode of the pickup modulates a high-frequency signal which is detected to produce a voltage output that corresponds to the amplitude of vibration.



Calibration factor of the capacitance-type vibration pickup as determined by two methods using a condenser microphone. The triangles represent the values obtained by the first method described in the text, except that a condenser microphone was used in place of the driven piston. The open circles and squares were obtained by the second method. The values at low frequencies were checked by optical calibration of the pickup, with results (black circles) that agreed to within 4 percent.

The purpose of the calibration procedure is to determine the value, M, of this ratio. Once M is known, the displacement (amplitude) corresponding to a given output voltage can be found from the relation $\xi = e_c/M$.

When a condenser microphone is used in calibrating a pickup, the response of the microphone must be known. Accurate determination of this characteristic is therefore an important part of the calibration procedure. The response of the microphone, which can be found by the reciprocity method,[4] is defined as $\rho = e_{oc}/p$, where e_{oc} is the voltage generated by the microphone when acted on by a sound pressure, p. Special methods have been worked out for measuring the response at very low and very high frequencies.[5]

Two methods for calibrating the capacitance-type pickup probe have been developed. In both, the sensitivity of the pickup, including its associated detecting circuit, is obtained from voltage ratio measurements and from the open-circuit response of the microphone.

The first calibration method (see footnote 2), makes use of a 20-cm³ cavity in which sound pressure is generated by a vibrating piston that projects into the enclosure. The sound pressure is measured with a condenser microphone. The piston displacement, ξ, and the sound pressure, p, are theoretically related by the formula, $\xi = -(V/\gamma S P_0)\, p$, where V is the volume of the cavity, γ is the ratio of specific heats for the gas in the cavity, S is the area of the piston, and P_0 is the barometric pressure. In the final step of the procedure, the cavity is not used; the probe is placed in proximity to the exposed end of the piston and the output of the detecting circuit observed. Since the amplitude of vibration (ξ) of the piston is now known, the last observation permits the calibration factor to be calculated.

In the second and more recent method (see footnote 1) the cavity is not needed; the diaphragm of a con-

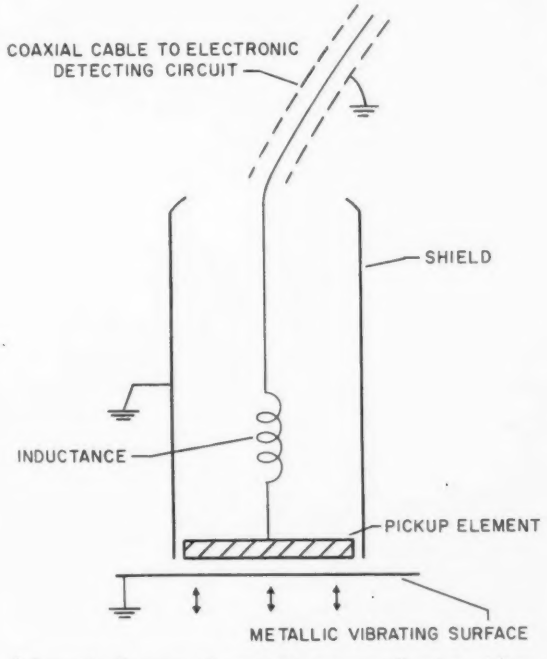
denser microphone is set in motion by applying an alternating voltage, with suitable d-c bias, to the microphone terminals. The capacitance pickup is then placed close to the diaphragm to measure its motion; it does this by detecting the change in capacitance between the diaphragm and the pickup electrode of the probe.

Although this method requires a pickup probe of special design, it is somewhat easier to carry out because the auxiliary apparatus is less cumbersome. Important features of the probe for use with this method are a perforated metal disk that forms the pickup electrode and a threaded shield that permits the probe to be screwed into the diaphragm end of the condenser microphone.

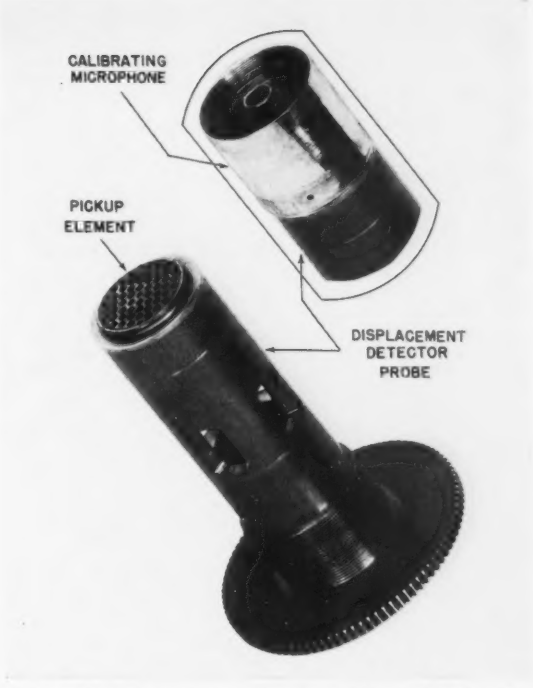
The calibration factor, M, of the probe and detecting circuit combination, in voltage output per unit equivalent linear displacement, can be computed from the equation:

$$M=\frac{S}{\rho}\left(\frac{e_c}{e}\cdot\frac{1}{C}\right)_{p=0} \qquad (1)$$

where S is the area of the microphone diaphragm, e_c/e the ratio of the detecting circuit output voltage to the microphone driving voltage, C the microphone capacitance (which must be measured), and p the sound pressure during the measurement of e_c/e and C. The condition, $p=0$, corresponds to zero acoustic load as seen by the microphone diaphragm; it is obtained in a separate measurement with the help of a quarter-wavelength tube.



Schematic diagram of capacitance-type vibration pickup probe. The probe is specially adapted for calibration with the help of a condenser microphone. Using this type of pickup, amplitudes as small as 10^{-9} cm can be measured; calibration was performed over the frequency range from 10 to 40,000 c/s.



***Below:* Capacitance-type vibration pickup, showing the perforated-disk pickup element. *Above:* The pickup is screwed into a condenser microphone, bringing the pickup element into a fixed relation with the microphone diaphragm for the purpose of calibrating the pickup.**

Using the first method, the calibration factor of the vibration pickup was measured over a frequency range from 50 to 10,000 c/s; with the second method, the calibration was performed from 10 to 40,000 c/s. In both cases, an independent check was made by optical calibration of the displacement detector. This was done at several low frequencies for which the displacement of an electrodynamic exciter was large enough to be measured with a microscope. The optical calibration points agreed with the values determined by the microphone methods to within 4 percent.

[1] The condenser microphone as a displacement detector calibrator, *by W. Koidan, J. Acoust. Soc. Am.* **29,** *813 (July 1957).*

[2] An acoustic method for the measurement of vibration amplitudes, *by W. Koidan, J. Acoust. Soc. Am.* **26,** *428 (May 1954).*

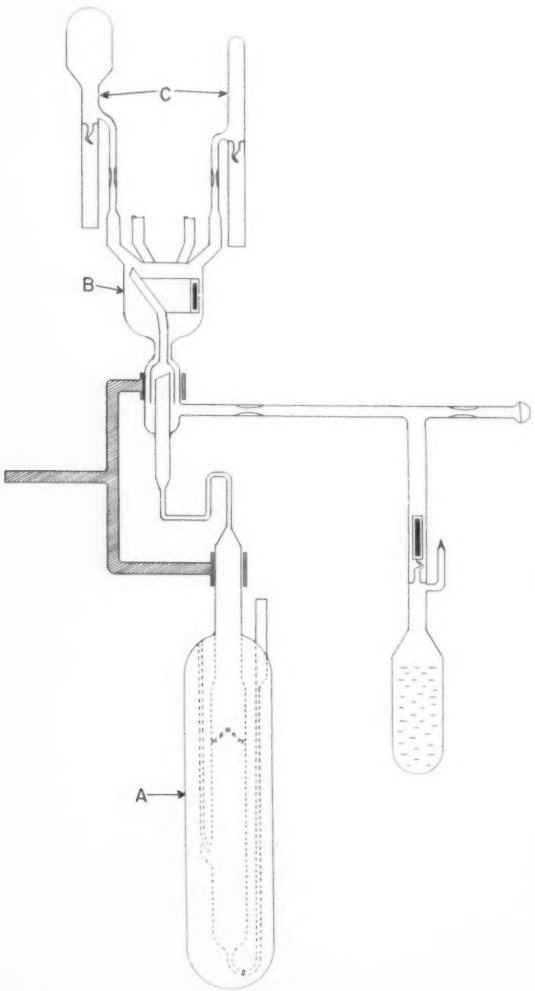
[3] Mechanical impedance of the forehead and mastoid, *by E. L. R. Corliss and W. Koidan, J. Acoust. Soc. Am.* **27,** *1164 (Nov. 1955).*

[4] Absolute pressure calibration of microphones, *by R. K. Cook, J. Research NBS* **25,** *489 (1940) RP1341.*

[5] Acoustic impedance of a right circular cylindrical enclosure, *by F. Biagi and R. K. Cook, J. Acoust. Soc. Am.* **26,** *506 (July 1954);* Pressure calibration of condenser microphones above 10,000 cps, *by B. D. Simmons and F. Biagi, J. Acoust. Soc. Am.* **26,** *693 (Sept. 1954).*

Purification by Fractional Melting

A PURIFICATION PROCESS for substances that are difficult to purify under standard conditions has been developed by the Bureau. The process, called "fractional melting" [1] because of its close analogy to fractional distillation, was devised by A. R. Glasgow, Jr., and G. S. Ross of the pure substances laboratory to meet the continuing demand for purer materials in scientific research. It has been applied to the purification of 2,5-dichlorostyrene, which is used as a "potting agent" in electronic components.



Assembly of fractional melting tube (A), distributor (B), and receivers (C) used in the fractional melting process. Because of the controlled, inert apparatus used, substances which are reactive in air may be easily purified; this is accomplished by flushing the glass container with a high vacuum system. After the tubing leading to the vacuum is sealed off, the sample is distilled into the fractional melting tube. In the melting cycle, the dissolved crystals flow from the cone to the distributing funnel into the final receiving ampoule.

Conducted in a closed, inert system under equilibrium conditions, the fractional melting procedure is well suited for the purification of substances that are corrosive, hygroscopic, toxic, or reactive in air. It has several advantages over the conventional fractional crystallization. These include easy separation of contaminants and convenient purification of small samples, with a high percentage of yield.

In general, fractional melting is a single-stage operation consisting of slow equilibrium melting of a crystalline mass formed by slow equilibrium freezing. The liquid sample is first placed in an ampoule and distilled into a fractional melting tube, where it is cooled to a temperature just below the freezing point. Beginning at the bottom, crystals grow slowly from this slightly supercooled liquid. During this gradual crystallization, the crystals formed reject the impurity until solidification is almost complete. Therefore, the bulk of the contaminant is included in the crystalline network at the top of the sample. For this same reason, the core of the crystal is uncontaminated while impurities are found in the crystal periphery.

When crystallization is nearly complete, the tube is inverted and heat is applied at the bottom. This causes the crystals with the highest impurity content—which are then in the lower end—to melt first. As other crystals gradually liquefy and flow downward through the crystalline network, liquid from the previously melted crystals bathes each succeeding crystal surface. Since fractions of the liquid are periodically drawn off from the bottom, the less pure material is progressively displaced by liquid of higher purity. Thus the final fraction is extremely pure.

Crystals are retained within the fractional melting tube chamber by a perforated glass cone. The liquid from the melting crystals flows through the cone into the distributing funnel, which directs the melted fractions into receiving ampoules. These are sealed off and removed from the system. The funnel can be rotated to various positions to fill one ampoule after the other.

For the starting operation, the glass equipment, consisting of a fractional melting tube, distributor, and receivers, is exhausted by a high vacuum system. Next, the glass tubing leading to the vacuum system is flame sealed. Following this, the sample is distilled into the fractional melting tube chamber and the ampoule, which originally contained the sample, is removed.

Constant temperature baths are used in both the freezing and melting sequences. The freezing and melting rates are controlled by using an appropriate bath and by varying the pressure in the silvered vacuum jacket. Ice and water slurries are used for samples freezing above 0°C, powdered carbon dioxide refrigerant for samples freezing above −50°C, and liquid nitro-

gen for substances freezing below −50°C. The temperature is regulated by means of a thermocouple inserted in the small closed glass tube connecting the sample container and the vacuum jacket.

Crystallization may be induced by thermal-shock seeding. In this method, the small amount of sample contained in the U at the bottom of the cell is frozen by cooling it with either powdered carbon dioxide or liquid nitrogen. Thus the first crystals form on the bottom and then grow upward.

When the crystallization process is nearly complete, the tube is inverted and placed in a special Dewar-type vessel for gradual warming. For samples of 98 percent and higher purity, the outer wall of the tube is kept at a constant temperature several degrees above the sample's freezing point; for lower purity samples (80 to 98 percent), the outer wall is warmed slowly from the lowest crystallization temperature to just above the freezing point of the sample.

For a maximum pure yield, it is important that the process of crystallization be extremely gradual because this enables the crystal to form without inclusion of surrounding impurities. Slow crystallization also produces larger crystals. These have a smaller ratio of surface area to mass, therefore the total amount of absorbed impurity on the crystalline faces is reduced.

As the final step in purification of a substance by fractional melting, a scientist seals off an ampoule containing the purified sample. Fractional melting is a single-stage process consisting of slow equilibrium melting of a crystalline mass formed by slow equilibrium freezing in a closed, inert system.

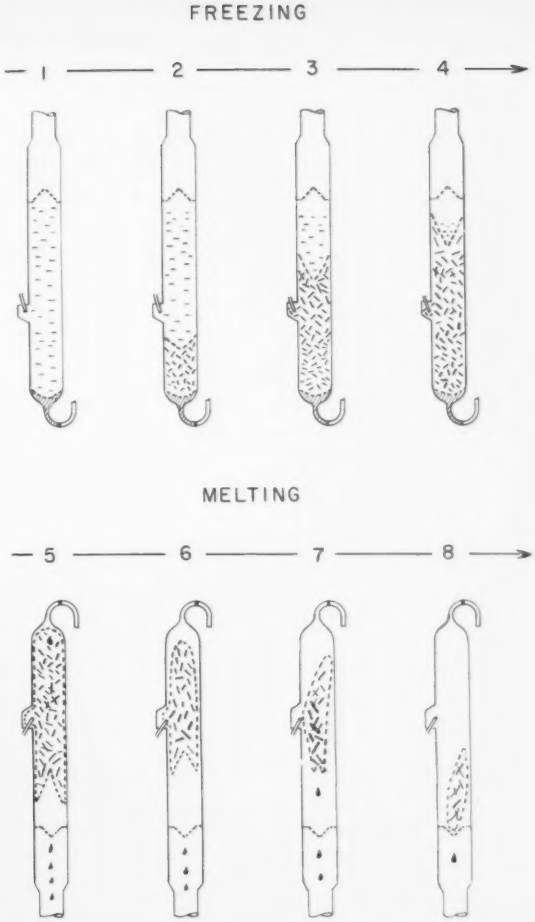


Diagram showing the freezing and melting stages of purification of the sample. Horizontal lines represent the sample in a liquid state, while diagonal lines represent the crystalline mass. After the substance has been completely frozen in the fractional-melting tube, the tube is inverted for gradual melting. The reason for this inversion is that the initial crystal growing at the bottom of the container forms without inclusion of impurities. Therefore the majority of the contaminants are contained within the crystalline mass at the top of the vessel. The transposed tube, then, has the more contaminated substance at the bottom. Upon heating, this facilitates easy removal of the impurity-containing crystals.

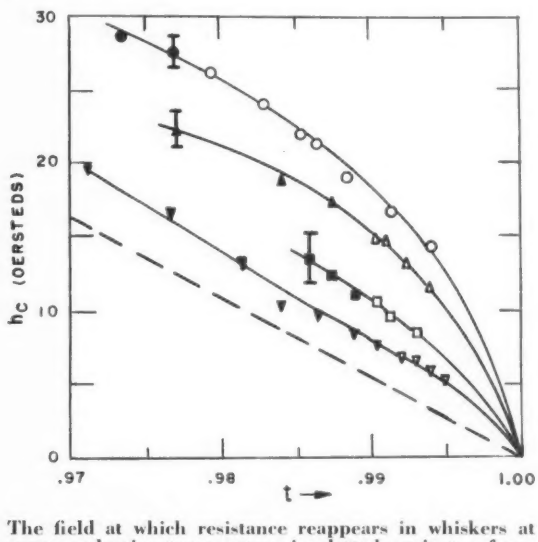
In earlier methods, the separation of the mother liquor from the pure crystals was difficult and ineffective. With the present equipment, however, the tube can be inverted, permitting the concentrated impurity content, which is retained in the crystals growing near the top, to be melted and retrieved first. This avoids unnecessary contamination of the pure substance and allows a larger percentage yield of highly purified material—approximately 99.95 percent pure.

[1] *For further technical information, see* Purification of substances by a process of freezing and fractional melting under equilibrium conditions, *by A. R. Glasgow, Jr., and G. S. Ross, J. Research NBS* **57**, *137 (1956) RP2703.*

Superconducting Transitions in Tin Whiskers

AT VERY LOW TEMPERATURES certain metals become superconductive, that is, they lose all electrical resistance. However, resistance can be made to reappear even at superconducting temperatures when a large electric current is sent through a superconductor or when a sufficiently strong magnetic field is applied. The Bureau has investigated these superconducting transitions at liquid-helium temperatures in microscopic tin filaments called "whiskers." This research, conducted by O. S. Lutes [1] of the cryogenic physics laboratory and sponsored by the Air Force, shows the mechanism by which a magnetic field restores resistance to a whisker in a superconducting state.

Since the results obtained with these small filaments differ markedly from those for larger wires, the present work has established the importance of size effects in superconductivity. A study of size effects provides information about the surface tension between superconducting and normal domains and about the penetration of a magnetic field at the surface of a superconductor.



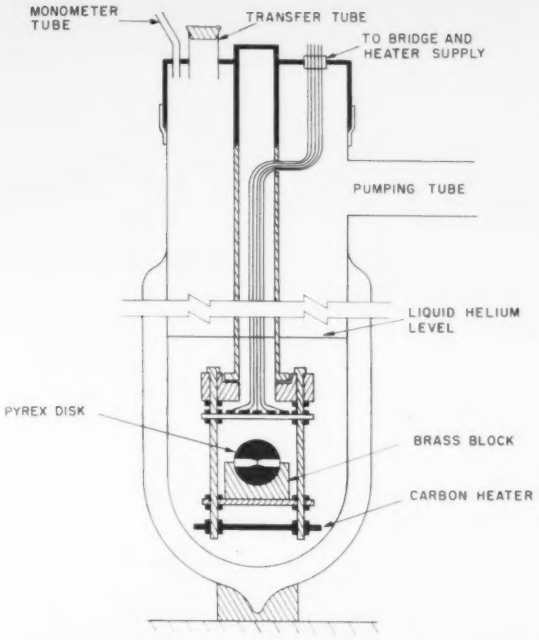
The field at which resistance reappears in whiskers at superconductive temperature is plotted against a function of temperature. This function is the ratio of the temperature under study to the zero-field transition temperature. The threshold curves were obtained in the investigation of superconductive transitions in tin whiskers. The field is seen to increase as the temperature is lowered beyond the transition temperature.

The first step in investigating the transition mechanism was to determine the magnitude of the magnetic field which destroys superconductivity (restores resistance) at various temperatures. The measurement of filament resistance at various field magnitudes was carried out by a relatively simple bridge method, but preliminary operations involved such complicated processes as growing the whiskers, designing a device for detaching and mounting them, providing a region of controlled temperatures, and applying a uniform magnetic field.

A technique that greatly accelerates the rate of whisker growth was employed to produce whiskers. The whiskers grew from the polished edge of a stack of tin-plated steel squares when a pressure of several thousand pounds per square inch was applied to the top of the stack. In this way filaments about 0.02 in. long and about 0.0001 in. in diameter were obtained.

The next problem was to detach these small filaments from the stack and mount them as circuit elements so that their resistance (or lack of resistance) could be determined. Because of their minute size, a manual operation was impossible. A special probe assembly was therefore designed. The assembly consisted of a short length of copper wire—the probe—soldered to a loop of resistance wire. All operations utilizing the probe were performed by a micromanipulator and viewed under a microscope. Wax was melted on the probe, which became hot when current was sent through the resistance loop. The probe was manipulated to contact the whisker and, when the wax hardened, to remove it from the surface and then, when the wax again melted, to mount it on a Pyrex plate. Silver paste was used to provide a contact between the whisker and the electrical leads.

The restoration of resistance at various temperatures was studied by applying a magnetic field parallel to the specimen axis. This field was produced by a three-coil system and was uniform over a large region. The mounted specimen was suspended in the magnetic field in a liquid helium bath. The temperature of the bath was controlled by the removal of excess gas. The vapor pressure above the liquid, as indicated by a manometer, gave a measure of the temperature in the location of



Cross-sectional drawing of the experimental arrangement used in the study of superconducting transitions in tin whiskers. The helium Dewar rests on the bottom of a liquid air Dewar (not shown). Beneath the surface of the liquid helium, a rotatable Pyrex disk is mounted on a brass block. The whisker is mounted on the disk between two silver paste electrodes, and alined with the direction of the applied field by turning the disk. At the bottom of the Dewar is a carbon heater used for "thermal stirring" of the bath. The sample and heater leads are brought up from the bottom of the Dewar inside a Pyrex tube; for simplicity, details of connections are not shown.

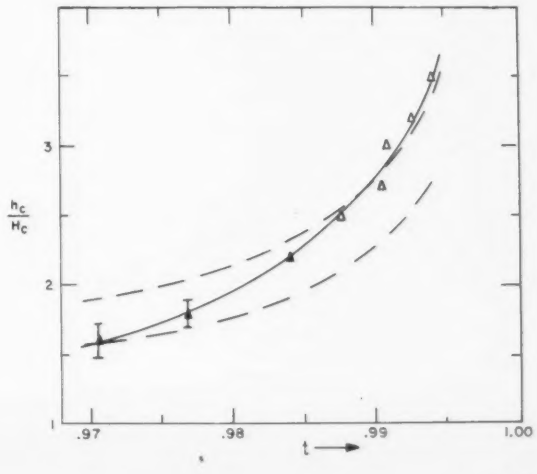
the whisker. Surrounding the helium bath with a Dewar flask prevented heat influx.

The magnetic field resulting in restoration of resistance was determined by maintaining a check on the resistance of the filament with a Mueller bridge. The resistance of the filament was read with a highly sensitive galvanometer used in conjunction with the bridge. Maintaining a specimen current of about 5 μa allowed satisfactory galvanometer deflection while limiting the induced field to a value that was negligible in comparison with the critical field.

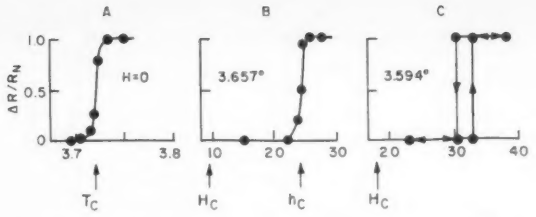
A resistance transition also occurs in the absence of a magnetic field. This type of transition was compared with the magnetically produced transitions occurring at lower temperatures in an effort to better understand the transition phenomena. The temperatures at which transitions occur in whiskers when no magnetic field is present were determined by varying the temperature in a zero field. Transition temperatures were found to be close to the accepted value, 3.730° K, for bulk natural tin; however, the whisker transitions were found to occur over a fairly wide temperature range. The character of magnetically produced transitions which occur at temperatures well below the transition temperature was found to be radically different: transitions become sharp and discontinuous and also exhibit a hysteresis effect—the curve of critical field versus temperature obtained in restoring resistance follows a different path than the curve obtained in going from the resistive to the superconducting state. This hysteresis disappears at temperatures sufficiently close to the zero-field transition temperature. In the temperature region where hysteresis is absent or of small extent the threshold curve is unambiguously determined and lies well above the curve for bulk tin. The ratio of whisker to bulk critical fields increases with temperature. For the thinnest specimen this ratio was about 5 at the highest measured temperature.

The investigators derived the penetration depth of the field at 0° K from the data for each whisker. The depth to which the field penetrates was found to depend on the normal electrical conductivity of the filament as estimated from the change in resistance at the transition.

Two theories of superconductivity predict size effects in thin wires. One, the London theory,[2] characterizes the properties of a superconductor by the depth to which a magnetic field penetrates at the surface of a bulk specimen. The other theory, that of Ginsburg and Landau,[3] explicitly considers the relation between magnetic field and the density of superconducting electrons. The latter theory allows for additional free energy terms that give rise to higher critical fields. The



Graph of the ratio of whisker field to applied field plotted against a function of temperature. Results obtained at the Bureau (experimental points), results predicted by the Ginsburg-Landau theory (solid line), and results predicted at two temperatures by the London theory (dashed line) are included. In each case the field ratio increases with temperature. Experimental points give a good fit to the Ginsburg-Landau curve. Neither the London curve for the lowest experimental temperature nor the curve for the highest temperature correspond with the Bureau's results.



Graphs showing the relation between resistance and temperature obtained in the investigation of superconducting transitions in microscopic tin filaments. (A) A function of the change in resistance plotted against temperature in degrees K for a zero field. (B) A function of the change in resistance plotted against the field in oersteds at a temperature of 3.657° K. (C) A function of the change in resistance plotted against the field in oersteds at a temperature of 3.594° K; this curve displays hysteresis.

Ginsburg-Landau theory also predicts second-order transitions for wires below a critical size and no hysteresis loss for such transitions. The temperature dependence of the critical field and the hysteresis behavior found by the Bureau are both in substantial agreement with specific predictions of the Ginsburg-Landau theory, as applied to small cylinders. A dependence of penetration depth upon the normal electrical properties is also permissible within the framework of this theory. Conversely, the London theory was found inadequate to describe the data obtained at the Bureau.

[1] *Now with the Minneapolis-Honeywell Regulator Co.*

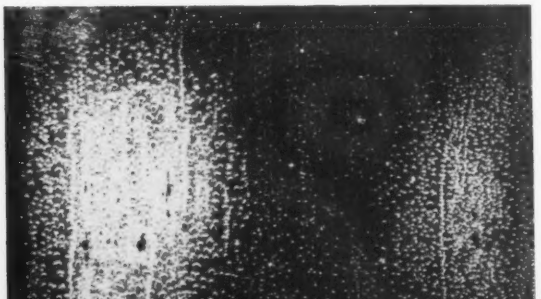
[2] The electromagnetic equations of the supraconductor, *by F. London and H. London, Proc. Roy. Soc.* [A] **149,** *71 (1935).*

[3] On the theory of superconductivity, *by V. L. Ginsburg and L. D. Landau, Exptl. Theoret. Phys. U. S. S. R.* **20,** *1064 (1950).*

Observation Concerning Metal Fatigue

AN interesting surface phenomenon occurring during metal fatigue has recently been observed at the Bureau's mechanical metallurgy laboratory. The observation provides a technique that promises to be of value in studying the effect of surface reactions on metal fatigue. Also, it may have practical application in the early detection of fatigue cracks.

Metals subjected to repeated or fluctuating loads sometimes break after many cycles of stress. This type of failure, referred to as fatigue, begins as a tiny crack that gradually progresses through the metal undergoing stress. Previously, time-lapse motion pictures of a fatigue fracture in an aluminum alloy had shown materials being extruded from the cracks in surprisingly large amounts, considering the size of the cracks.[1]



Comparatively large and numerous bubbles have formed under the transparent tape applied to the stressed specimen of an aluminum alloy. The metal had been stressed for 100,000 cycles before the tape was applied, and several fatigue cracks had developed. An additional 2,000 cycles of stress produced the bubbles shown here.

In an attempt to obtain some of this material for identification, Irene C. Minor applied a piece of transparent pressure-sensitive tape to the surface of a torsion fatigue specimen. Fatigue cracks had already been induced in the metal by several thousand cycles of reversed stress. When the specimen was then stressed for an additional thousand cycles, small bubbles formed under the tape.

A series of investigations disclosed that bubbles formed as soon as detectable cracks were present. Even when the cracks were so small they could be seen only with a microscope under special lighting, the bubbles were large enough to be readily seen with the unaided eye. For this reason, it appears that this observational technique may be used to detect the onset of fatigue cracking.[2]

Apparently, the bubbles can be produced with some metals and not with others. In the experiments thus far, the tendency of various stressed metals to form bubbles was observed as follows:

5052-H34 aluminum alloy	strong
2024-T3 aluminum alloy	strong
Mild steel (cold rolled)	moderate
Stainless steel	very weak
Brass	none
Zinc	none

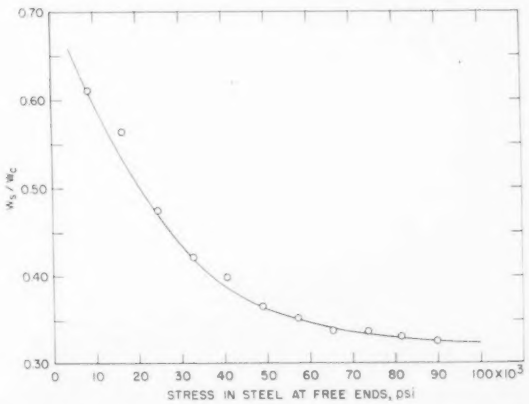
These differences suggest that the phenomenon is due to surface reactions; however, further studies must be made before the mechanism of the effect can be fully explained.

[1] *See* Motion pictures of metal fatigue, *NBS Tech. News Bul.* **40,** *153 (1956).*

[2] *A patent for this process has been applied for (NBS serial 682,071).*

Crack Widths in Concrete

IN DESIGNING a reinforced concrete structure, the engineer takes into account the fact that cracks will eventually develop in the structure. These cracks expose the reinforcing bars to the atmosphere with consequent corrosion that can weaken the entire structure. Recent evidence [1] uncovered at the Bureau, however, indicates that these cracks are narrower near the surface of the reinforcing bar than at the outside concrete surface, thus exposing less of the bar to corrosion than was heretofore believed. These measurements, made by D. Watstein and R. G. Mathey of the structural engineering laboratory, are expected to be of value to the structural design engineer in making better use of existing design data, with consequent savings in materials.



Graph of the ratio of crack at surface of steel reinforcing bar (W_s) to crack width at surface of concrete (W_c) versus the stress in the steel bar.

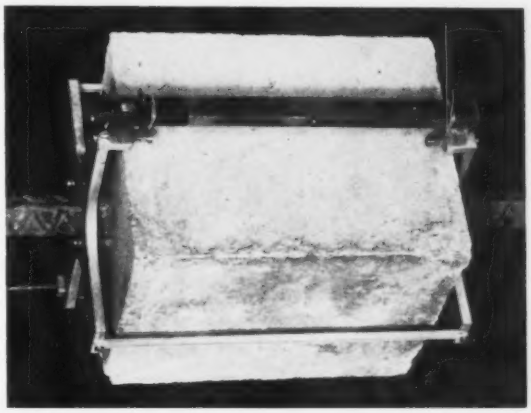
Conventionally reinforced concrete normally develops numerous fine cracks when the tensile strains caused by loads, drying shrinkage, and thermal changes combine to exceed the limit of extensibility of concrete. Only through careful design and proper selection of well-designed deformed reinforcing bars can the designer limit the width of these cracks to safeguard the steel bars against corrosion. It had been previously believed that the cracks were, on the average, nearly uniform in width from the surface of the concrete to the surface of the bars, and this assumption was followed in designing structures. Since there was indirect evidence that this assumption was not entirely true, the Bureau undertook a more detailed study of the variation of width of cracks.

The crack width measurements were made on tensile bond specimens designed to simulate a portion of the tensile zone of a reinforced concrete beam between two successive cracks. Each specimen was essentially a prism of concrete 8 in. long with a reinforcing bar embedded along the longitudinal axis. A tensile force was applied to the ends of the bar. The extension of the embedded portion of the bar, the over-all extension of the concrete prism at points $\frac{3}{8}$ in. from the surface of the bar, and the over-all change in length of the exterior surface of the prism were determined.

Since the length of the exterior surface of concrete remained substantially constant during the test, the over-all extension of the embedded bar was taken as the width of crack measured at the surface of concrete. The difference between the extension of the embedded bar and that of the concrete adjacent to the bar was assumed to give the width of crack at the surface of the bar.

The ratio of the width of crack at the surface of the bar to that at the exterior surface of concrete has been plotted against the applied stress, to provide the engineer with the necessary design information. This reduction of crack width in the vicinity of the surface of reinforcing steel was observed only for deformed bars; no measurable reduction of crack width was observed with smooth round bars.

[1] *D. Watstein and R. G. Mathey*, Evaluation of width of cracks in concrete at the surface of reinforcing steel by means of tensile bond specimens, *RILEM Symposium on Bond and Crack Formation in Reinforced Concrete* (*Stockholm, 1957*). (*RILEM stands for Réunion Internationale des Laboratoires d'Essais et des Recherches sur les Matériaux et les Constructions, 12, Rue Brancion, Paris, France.*)



Tensile bond specimen under test. Indications are that the cracks that occur in concrete are narrower near the surface of the steel reinforcing bar than at the outside surface of the concrete, thus exposing less of the bar to atmospheric corrosion and consequent weakening than heretofore believed.

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SUMMER CAREER PROGRAM aids in scientist recruitment

A PROGRAM which gives students an opportunity to become acquainted with a Government research laboratory during their summer vacation periods is helping the National Bureau of Standards meet its increasing demand for high-caliber technical graduates.[1] Having discovered for themselves the advantages of a professional career at the Bureau, 174 of 1957's record enrollment are maintaining NBS affiliation: of the 236 students employed at the Washington laboratories in the past summer, 44 are still on full- or part-time duty and 130 who plan to return to the Bureau have been granted leave without pay to continue their education. One-half of the 208 students employed in 1956 were included in last summer's program. Another 57 had remained on duty permanently (table 1). The program, inaugurated in 1948, was extended to the NBS laboratories in Boulder, Colorado in 1956 where it has already resulted in a number of permanent appointments.

Summer students learn about purification by crystal growth from John Torgensen. This demonstration was part of a tour designed to familiarize the students with the scope of the Bureau's work.

Thus the Student Trainee Program, which enables college men and women to apply their education in jobs selected according to their interests, is proving mutually beneficial to employer and employee. Actual participation in laboratory work has been found to be not only an incentive for continuing scientific studies but also a help to the student in formulating career objectives and in integrating classroom work with actual laboratory experience.

Besides being successful as a long-range recruitment plan, the Student Trainee Program demonstrates the ability of younger employees to make direct contributions to the research program. For example, written evaluations by supervisors at the Washington laboratories showed that almost 85 percent of the 1956 trainees did above average work. Outstanding work was performed by several students. Summer student Robert C. Burton, now a permanent employee, made a valuable contribution in developing a mathematical theory for design of experiments, for which he received a Superior Performance Award of $300. He was co-author of a technical paper on the subject. Some other 1956 students with papers to their credit are James A. Miller, physicist from the University of Maryland, Charles T. Zahn, physicist from Princeton University, and Herbert D. Dixon, chemist from North Carolina State College.

A sampling of the 236 students employed at NBS Washington during the past summer. *Top:* Charles A. Gray, who worked in the pure substances laboratory, determines the freezing point of a liquid. Mr. Gray, a 2d year student in chemical engineering at Cornell, was a 1956 science competition winner. *Center:* A top contestant in a 1957 national science competition, James B. Compton, investigated methods of applying ohmic contacts to semiconductors. He is now a freshman at the University of Colorado. John M. Smith, a mathematics student from the University of Richmond, spent his summer programing codes for one of the Bureau's high-speed electronic computers. Thomas K. Faison, Jr., an engineering student from North Carolina State, planned and carried out an experiment on the acoustic properties of tiles. Here he places the tiles in a large cupboard where they will be exposed to a spray of soot from a revolving blower. Marjory Schoonover, a senior in chemistry at William and Mary, observes the radiation above a pool of water containing radioactive cobalt. Miss Schoonover was engaged in a project to determine the effect of radiation on the structure of impregnated rubber. *Bottom:* Richard M. Lee, a University of Michigan physics student, determines the intensity of a radioactive source as part of his work in the gamma-ray laboratory. He is using an electroscope to compare the source with a standard of known intensity. John S. Gallagher, a graduate student from Johns Hopkins University, has been studying low-temperature phenomena at the Bureau. Here he uses liquid nitrogen as a coolant. Eli White, a dental student at the University of North Carolina, tests the color stability of materials used in dentures by exposing samples to a sunlamp. Robert H. Armsby, a 1956 National Fair finalist, adjusts apparatus in the free radicals research laboratory designed to measure the velocity of free-radical recombination. He is a sophomore in engineering physics at Cornell.

The valuable work which students turn out has received recognition outside the Bureau also. P. Michael Fulcomer, Jr., a 1957 graduate of Northwestern University received the Junior Engineer Award for 1957 of the Washington Society of Engineers. The acknowledgement was made for work he did as a student at the Bureau on standardizing electronic circuits. Mr. Fulcomer, who was enrolled in the Trainee Program as a cooperative student for 5 years, is now a permanent employee of the Bureau's engineering electronics laboratory.

During the past summer, students aided in projects ranging from radio propagation studies to developing test methods for acoustic tiles. Programing problems for automatic computers, standardizing isotopes used in medicine, measuring the velocity of free-radical recombination, and designing cryogenic equipment were just a few of the activities engaged in by the young scientists. About 95 percent of the 1957 trainees received a "good" or "excellent" performance rating after careful review of their work.

Among those who turned in outstanding performances was Barry M. Casper, a chemistry major from Swarthmore College. Mr. Casper has spent two summers at the Bureau working in the mineral products laboratories. As a high school science honor graduate in 1956, he did independent research on growing titanium dioxide particles, which resulted in a patent application. During the past year he worked out a method for measuring magnetic susceptibility to its final stages.

Another valuable summer scientist is David W. Oliver, who has been employed at the Bureau each summer since 1954. He holds his bachelor's and master's degrees in physics from Virginia Polytechnic Institute and is presently studying for his Ph. D. at Massachusetts Institute of Technology. For two summers he was employed in the electrical measurements laboratories, where he had some of his work published. In 1956 Mr. Oliver transferred to the neutron physics laboratory, where he investigated neutron penetration in water. A paper covering this work will soon be published. During the past summer he designed an electrostatic quadrapole strong focusing lens to be used with the Van de Graaf electrostatic generator. A successful design for the Van de Graaf beam viewer depended to a great extent on suggestions offered by this student.

Work in solid state physics by another graduate student, David C. Ailion of the University of Illinois, is soon to be published. Mr. Ailion came to the Bureau in 1955 when he was a junior in physics at Oberlin. His work during the past summer included theoretical calculations of the X-ray scattering of indium-antimonide crystals. By comparing his calculations with experimental results, a greater understanding of semiconducting materials was obtained.

TABLE 1. *Status of 1957 summer students maintaning Bureau affiliation* [a]

	Leave without pay	Part time	Full time	Total
Student trainees	88	22	7	117
Junior professionals	42	3	12	57
Total	130	25	19	174

[a] 236 students were employed in the Washington program.

Fred J. Burmont is a student trainee in electronic engineering at the Boulder Laboratories. A freshman at the University of Colorado, he joined the staff working full time in the summer of 1957. He is now averaging 10 hours a week assisting with computations for ionospheric physics research. He is shown here at a scaling table obtaining numerical values from film records of vertical-incidence ionospheric soundings.

The Student Trainee Program supplements on-the-job experience with a series of lectures and tours designed to familiarize the summer employee with the research projects carried on throughout the Bureau. During the past summer, for example, details of the free-radicals research program were presented to the students. They were given the opportunity to view computer facilities, reactors, the solar furnace, and experiments on purification and high temperature physics, among other research work.

To gain eligibility on the register from which appointments to the program are made, college men and women must pass a written Civil Service Examination for Student Trainees. At the high-school level, a limited number of direct appointments are offered winners in the Westinghouse Science Talent Search and other national science competitions. A student who has taken part in the program and is recommended by his supervisor may return each summer while he is completing his education.

Trainee appointments are limited to science majors planning careers in the fields of research carried on at the Bureau. During the past summer the number of physics students was over 100, while chemists and engineers numbered about 50 each. Completing the Washington roster were 25 mathematics majors, 5 metallurgy students, and 1 geologist. The Boulder laboratories had 25 participants: 10 physicists and 15 engineers (table 2).

TABLE 2. *Distribution of students in the summer training program by major field of study*

	NBS Washington	NBS Boulder
Physics	101	10
Chemistry	50	
Engineering:		
Electrical	25	13
Mechanical	19	2
Others	10	
Mathematics	25	
Metallurgy	5	
Geology	1	

TABLE 3. *Distribution of students in summer training program by grade level*

	NBS Washington	NBS Boulder
GS–2 ($2960)	22	2
GS–3 ($3175)	81	4
GS–4 ($3415)	58	16
GS–5 ($4480)	48	3
GS–7 ($5335)	23	
GS–9 ($6250)	4	
Total	236	25

Of the 261 students employed at the two locations last summer, 183 were student trainees and 78 were junior professionals (table 3). The trainee group ranges from high-school graduates entering at the GS–2 level ($2960 per year) to students who have completed their junior year in college at the GS–4 level ($3415). Graduates who return to the Bureau receive a GS–5 rating ($4480) and those who are employed in a permanent capacity are advanced to a grade 7 ($5335) after 3 months, if they have qualified under a special training agreement during the preceding summer so that their summer work experience can be counted toward promotion. Graduate students are also accepted for summer employment, a master's degree qualifying scientists or engineers for a GS–7 and half the required Ph. D. work for a GS–9 ($6250).

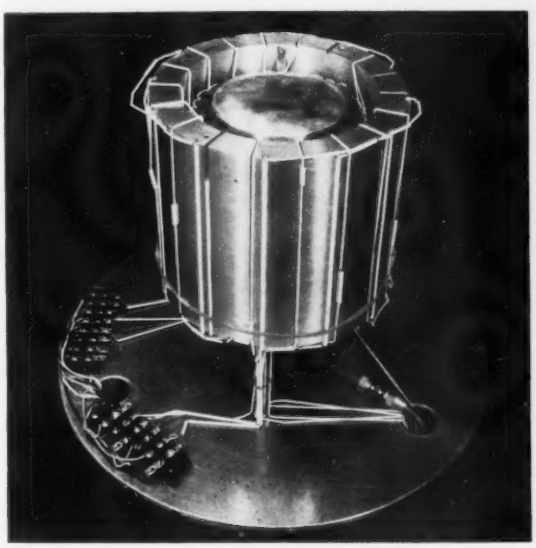
[1] Summer careers for science students, *NBS Tech. News Bul.* **40**, *132 (1956)*.

An award for an important contribution to the field of experimental design was presented to student trainee Robert C. Burton. William Connor (second from left) of the Statistical Engineering Section presents the award. Churchill Eisenhart (left), Chief of the Statistical Engineering Section, and Edward Cannon, Chief of the Applied Mathematics Division, look on.

Precise Adiabatic Calorimeter

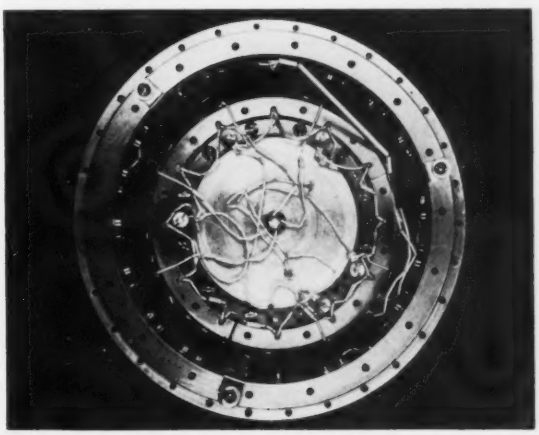
AN ADIABATIC CALORIMETER providing high precision within the temperature range from 30° to 500° C has been developed by E. D. West and D. C. Ginnings [1] of the Bureau. Highly integrated temperature controls, and a design based on systematic error analysis make possible 0.1 percent accuracy over most of the temperature range. The instrument is useful in measuring heat capacities of the solid and liquid phases of substances which have numerous phase transitions and therefore may reach equilibrium too slowly to permit measurement by the usual furnace-ice calorimeter technique. Obtaining heat capacities is one of the primary ways of acquiring precise values for the binding energies in molecules and the variation of energy content with molecular structure.

The calorimeter was developed in connection with a project, sponsored by the U. S. Bureau of Mines, for measuring the heat capacity and heat of fusion of sulfur. Accurate measurements of these quantities are needed between 30° and 500° C in order to determine the thermodynamic properties of sulfur in its standard state. These properties are needed to predict the equilibria of chemical reactions in petroleum refining which involve elemental sulfur, undesirable in most industrial applications. Knowledge of the free energy, entropy, and other thermodynamic quantities of the reaction system at various temperatures make it possible to gage the irreversibility of the process used to remove the sulfur. Until now accurate thermodynamic data on sulfur have been lacking because of the difficulty of calorimetric determinations on a material of such complex behavior.



Ideally an adiabatic calorimeter loses no heat to its environment. In making measurements the calorimeter is heated over a small temperature interval while the temperature of the surrounding area is kept as close as possible to that of the calorimeter.

The present apparatus consists of two basic parts: The calorimeter proper, where energy added is accurately accounted for, and a surrounding adiabatic jacket which prevents gain or loss of heat. The calorimeter includes a system of silver radiation shields and an aluminum container which can be removed for filling without disturbing the leads and thermocouples attached to the silver. Cylindrical in shape the sample container is 2 in. high, and has a diameter of 2 in. It is made of solid aluminum, bored with a large number of small holes less than 5 mm in diameter for containing the sample material. This creates a web of metal so that no part of the sample is more than 2.5 mm from a good thermal conductor, and enables the calorimeter to reach the necessary thermal equilibrium quickly. The sample container is heated by three heating coils placed in holes in the container. A platinum resistance thermometer is inserted in a hole in the center for the accurate determination of temperature changes.



Left: **Aluminum guard surrounding the assembled jacket and adiabatic calorimeter container. The jacket is enclosed in this cylinder to facilitate operation at high temperatures.** ***Above:*** **Top view of a partially assembled calorimeter. The material being investigated is placed in an aluminum container (center) to which are connected silver shields for temperature uniformity. Supporting and surrounding this container and shield system is the adiabatic jacket which reduces temperature gradients on the container, preventing heat transfer to and from the inner portion. Numerous thermocouple wires are distributed throughout the apparatus. The platinum resistance thermometer is located in the center of the sample container.**

Around the container and its shield system is an adiabatic jacket which minimizes heat transfer from the container. To minimize heat transfer, the inner

surfaces of the jacket and the outer surfaces of the calorimeter are of silver. The jacket is encased in a "guard" whose temperature is about the same as that of the jacket; this reduces the power required in the jacket and the consequent temperature gradients. Operation at the highest temperatures is facilitated by enclosing the guard in another heated aluminum cylinder.

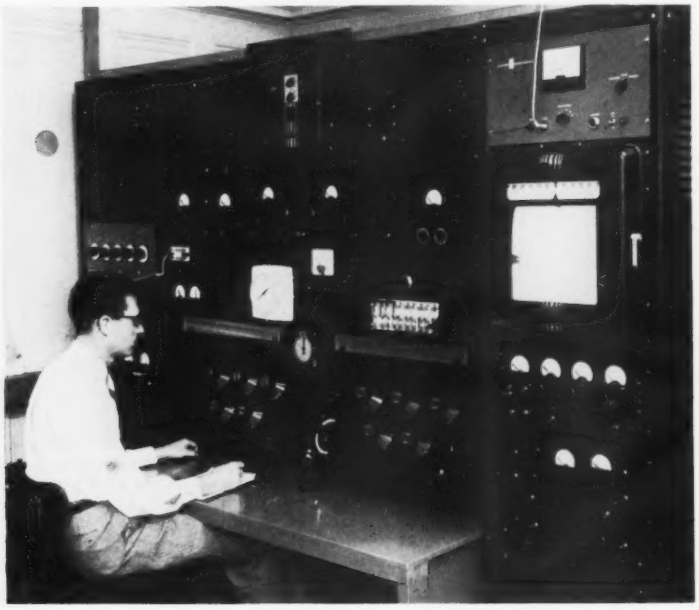
The greatest problem in measuring heat capacity with an adiabatic calorimeter in this temperature range is the heat leakage error which results from unknown experimental deviations from the ideal condition. To eliminate this error, two heat capacity experiments, one with an empty calorimeter and the other with the calorimeter containing the sample, are performed. Those errors, such as heat leakage, which have the same absolute value in both experiments, cancel out.

The temperature differences between the calorimeter and its jacket are measured so that heat losses may be evaluated. Any error in measuring these differences must be identical in both the empty and full experiments. For this reason, 2 thermopiles (consisting of 10 thermocouples each), connected in series between the jacket and the calorimeter, are frequently compared to detect any circumferential gradients. For maximum reproducibility, the thermopile junctions are not disturbed when the sample container is removed for filling.

The automatic control system not only records and regulates the jacket temperature but computes required corrections; this enables a single operator to handle the equipment.

The temperature control system incorporates three types of control action. First, "proportional" control changes the power supplied to the jacket by the amount proportional to its temperature difference from the calorimeter. Second, "automatic reset" control reduces gradually the average of this temperature difference to zero. Third, "rate" control keeps the time response of the controller as short as possible without causing sustained temperature oscillations. These factors are set by the operator in the external control system in order to provide the best temperature control consistent with short-time response.

The basic part of the controller system itself consists of three commercially-available components: A breaker-type amplifier, a recorder, and a control unit. The system takes the error signal from the thermopile in the jacket, amplifies and records it, and then adjusts the bias on a type 6AS7G electron tube according to the preselected controller factors. Two auxiliary circuits improve control at the beginning and end of the heating period. A simple electronic analog integrator is used to evaluate the small heat leakage due to deviations of the controlled temperature from the ideal.



An integrated, automatic control panel makes possible a 0.1-percent accuracy for the adiabatic calorimeter. The automatic control not only records and regulates temperature but computes required corrections. This enables a single operator to handle the equipment.

Estimating the average uncertainty on the temperature difference from all causes to be 0.001° at 400° C and considering a typical 40-min experiment, the heat loss due to this uncertainty is equivalent to 0.08 percent of the heat capacity of Al_2O_3, which was used in checking the performance of the calorimeter. The measurements of the heat capacity of Al_2O_3, the material selected by the Calorimetry Conference as a heat capacity standard, agree to 0.1 percent with accepted values.

[1] *For further information, see* An adiabatic calorimeter for the range 30° to 500° C, *by E. D. West and D. C. Ginnings, to be published in J. Research NBS.*

Dimensional Stability of Dentures

DENTURES are now being made to a considerable extent from self-curing resins. These resins cure without the application of heat, and they have properties of dimensional accuracy and stability that are equal to or better than those of the older heat-cured resins. Although similar to the methyl methacrylate materials used for many years, the self-curing resins differ in that accelerators have been added to the resin monomer or liquid. The accelerators promote free radical formation which causes the polymerization of the resin to be initiated at room temperatures.

As part of a general program for studying the basic properties of dental materials, the Bureau recently undertook an investigation of the relative dimensional stability of the two types of dentures. Dentures made from both materials were measured over a 2-year period. It was found that the magnitude of dimensional changes of both self-cured and heat-cured dentures was small, seldom exceeding 0.003 in. According to patient reaction, the slight changes did not affect the serviceability of dentures made from either material. The investigation was conducted by C. L. Burns, George Dickson, and W. T. Sweeney of the Bureau staff, working with Dr. W. E. Mowery, a guest worker from the Veterans Administration.[1]

TABLE 1. *Curing shrinkage of denture base resins*

		Percent
Self-curing materials	Dentures	0.27
	Blanks	.25
Heat-curing materials	Dentures	.43
	Blanks	.35[a]
		.34[b]

[a] Cured 9 hours at 160° F.
[b] Cured 1½ hours at 160° F and ½ hour at 212° F.

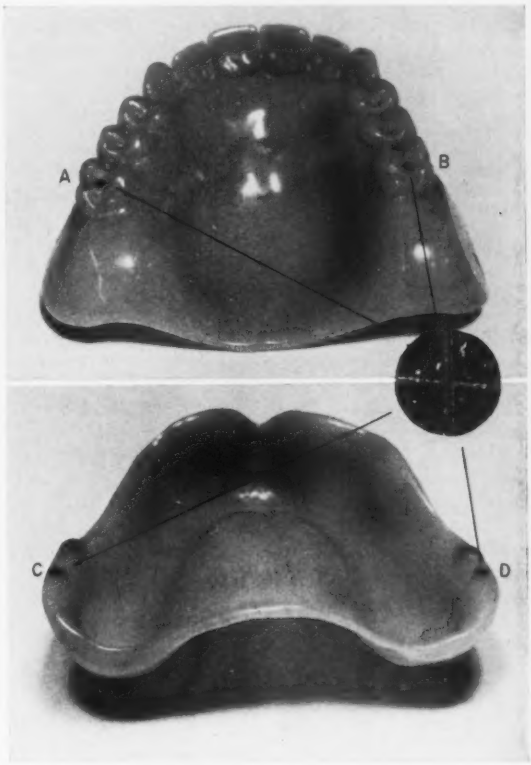
Specimens used in the experiment were fabricated in three Veterans Administration hospitals and at the NBS dental research laboratory. To provide reference points for determination of dimensional changes, ⅛-in. long, stainless steel pins ruled with fine cross marks were cemented in the last molars of the dentures, and in the rims or flanges on the opposite side. Measurements of the distances between reference points were made on a toolmaker's microscope to the nearest 0.0001 in.

On the dentures made at the Bureau, readings were taken on the waxed-up models before processing; after removal from the cast; just before insertion; at 30-day intervals for 6 months after delivery to the patient; and then at 6-month intervals. The VA dentures were first measured just before insertion and then on the same schedule; therefore, curing shrinkage of these specimens could not be calculated.

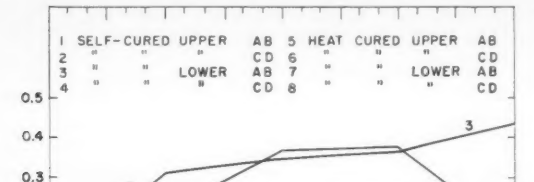
To supplement the data available on curing shrinkage, readings were taken on a series of technique denture blanks with only the last two molars in place. The difference between the waxed-up measurement and the measurement after removing the cured denture from the cast was taken as the curing shrinkage. Two heat-processing methods were used. The self-curing materials were processed without application of heat according to the manufacturer's instructions.

The study of curing shrinkage showed (1) that the heat-cured materials have a greater average curing shrinkage, and (2) that the method of heat processing has little effect on the amount of shrinkage (see table 1). That the shrinkage of the self-cured dentures would be smaller was anticipated as their lower polymerization temperature involves less thermal contraction.

In the study of dimensional changes of the dentures while in use, the measurement made just before insertion was taken as the zero reading, and all values were calculated with that measurement as a reference point. Both upper and lower dentures made with self-curing



Stainless steel pins in place on an upper denture used in the investigation. Dimensional changes between the last molars (AB) and between flanges (CD) can easily be measured under a toolmaker's microscope. At periodic intervals a reading is taken by means of the fine cross marks in the pins.



Average dimensional change while in use of self-cured and heat-cured dentures over AB (molar to molar) and CD (flange to flange) dimensions.

resins showed dimensional changes at a gradually decreasing rate over the first 6 months. The heat-cured upper dentures showed no significant changes throughout the first 6 months. During this period heat-cured lower dentures increased by approximately 0.44×10^{-3} in. per month over the molar dimensions, and 0.73×10^{-3} in. per month over the flange dimensions.

The results show that variations in dimensional changes in both self-cured and heat-cured dentures occur while in use. However, the magnitude of these variations is not large; in almost all cases the averages are within the range of -0.1 to $+0.4$ percent. The average expansion of the self-cured resins while in use was slightly greater than that of the heat-cured materials. This could be the result of lower sorption of water during processing, and higher sorption and expansion during use. Also, in most instances, the change in dimension from molar to molar was larger percentagewise than the change from flange to flange.

In general, individual dentures showed the greatest dimensional changes during the first month. Previous experiments have demonstrated that dimensional changes of approximately 1 percent can be produced in dentures by increase in water content.[2] Possibly, the variations from one denture to another while the dentures were in use were caused partially by differences in water content. Such differences could be attributed to the varying conditions under which the dentures were used.

[1] *For further technical details, see* Dimensional stability of denture base resins, *by W. E. Mowery, Claire L. Burns, George Dickson, and W. T. Sweeney, J. Am. Dental Assoc. (in press).*

[2] Acrylic resins for dentures, *by W. T. Sweeney, G. C. Paffenbarger, and John R. Beall, J. Am. Dental Assoc.* **29**, 7 *(1942).*

Cooling Electronic Equipment

AN IMPROVED METHOD for cooling electronic equipment on board ship has been under study at the Bureau. The method is based on transferring heat from the equipment cabinet through an intermediate coolant to sea water as the ultimate heat sink. Although undertaken for the Navy Bureau of Ships by P. Meissner of the Bureau staff to solve a special design problem in heat transfer, this technique could be applied to other than shipboard equipment, and tap water could be used instead of sea water.

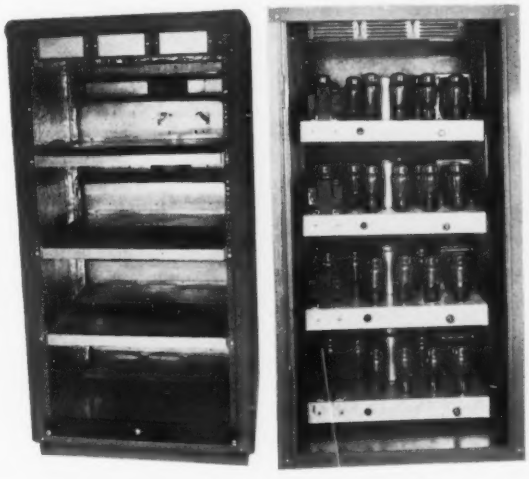
The rapidly increasing use of electronics aboard modern naval vessels has placed increased demands on shipboard cooling equipment. Present-day equipment relies for cooling primarily upon compartment air provided by the vessel's ventilating and air-conditioning system. The heat generated by these electronic devices imposes a burden on the ship's facilities and could subject the equipment to dangerous overheating in the event that the cooling system should be shut down in an emergency. In addition, the exhausting of heated air into the equipment compartment constitutes a hazard to operating personnel. A solution to these problems can be achieved by transferring heat from the equipment to sea water through an independent cooling system, rather than relying upon compartment air.

The study was concerned with a system that would be readily applicable to existing equipment of conventional construction. Present equipment is cooled primarily by air convection. If the equipment cabinets were enclosed and the air within the cabinet recirculated, a closed forced-convection system could be obtained. An air-to-liquid heat exchanger located within the cabinet could transfer heat from the air to an intermediate coolant, which, in turn, would give up its heat to sea water. By using an intermediate coolant, such as fresh water, the practice of piping sea water about the vessel could be avoided. The feasibility of this method depends largely on whether the equipment can be maintained at safe operating temperatures in locations where sea water is at its warmest.

The temperature of sea water ranges from $-2°$ to $+30°$ C. The intermediate coolant is therefore available at an upper limit of about 35° C, while cooling air can be supplied to the equipment at about 43° C. The temperature differentials are necessary for the efficient operation of the heat exchanges. Since there are many military-approved components suitable for operation at 43° C, this temperature would seem to be a safe upper limit. However, the temperatures of components inside large, dense equipment may be much higher than for components operated singly out in the open. Since

natural convection cannot be relied upon, the application of forced convection was investigated.

Examining the thermal characteristics of electronic components reveals that they can be grouped roughly into two broad categories. Such components as capacitors, transistors, and semiconductor diodes are restricted to the lower operating temperatures, but generally produce little or no heat. The major heat-dissipating components, such as tubes, transformers, power resistors, and dynamotors, are usually less sensitive to high temperatures. To minimize heating of the more sensitive components by the major heat sources, the two classes of components are arranged on opposite sides of a metal sheet. The cooling air is forced to flow through perforations in the sheet around the base of each heat-producing component. Thus, the cool incoming air below maintains the sensitive components at the lowest possible temperature, and is still available at nearly the inlet temperature to cool the heat-producing components above. The heated air is then drawn through the air-to-liquid heat exchanger, cooled, and recirculated within the cabinet.



Left: **Interior view of modified equipment cabinet—with all chassis removed—showing internal design for heat dissipation. This is part of the equipment used for investigating forced-air cooling techniques. In this cabinet, all openings are blocked off, exhaust hoods have been installed for removing warm air, the sides are insulated with a 1-in. layer of glass wool covered with aluminum foil, and sheet metal trays have been put in to support chassis and to provide flow paths for incoming air.** ***Right:*** **Test console, with back cover removed, all chassis in place. When equipment is turned on, and cool air is flowing in, air temperature just above lowest chassis is 49° C and increases to 67° C at top of cabinet. Chassis temperatures range from 57° to 90° C, plate transformers from 85° to 96° C, filament transformers from 96° to 111° C, and capacitors from 67° to 101° C. Highest temperatures of all occur in localized areas on the tubes; temperature of these "hotspots" may range from 184° to 196° C.**

It is not difficult to achieve the desired sequential airflow pattern, since much existing equipment already incorporates the necessary component part grouping to a considerable degree. In the case of standard chassis construction, it is customary to mount vacuum tubes and transformers on the upper side of the chassis, while such smaller components as capacitors, diodes, and low-wattage resistors are mounted underneath. The required airflow pattern is easily obtained by drilling holes through the chassis around the base of each heat-producing component, enclosing the bottom of the chassis, and supplying air under slight pressure to the space within the chassis. One component which does not generally fall into the desired grouping is the electrolytic capacitor. Because of its large size, this component is frequently mounted on top of the chassis, and is thereby subjected to high temperatures resulting from its proximity to vacuum tubes and other sources of heat. Where it is necessary to mount this component above the chassis, it can be kept cool by surrounding it with a reflective metal baffle and placing a few perforations through the chassis around the base of the capacitor. A similar procedure can be followed in the case of heat-producing components which, for electrical or mechanical reasons, must be mounted beneath the chassis. Variations of this general method can be followed to establish the desired airflow pattern in other forms of electronic equipment construction.

The above method of applying forced convection was developed and evaluated experimentally on a console containing a number of conventional components assembled using standard chassis construction. It was determined that all components could be kept within safe operating temperatures with cooling air at an inlet temperature of 43° C. An air temperature rise of 10° C was obtained, using an airflow rate of approximately 200 ft^3/min. Electrical power input to the console was about 1,200 watts. The console was completely closed and insulated to reduce the interchange of heat between the console and its environment. An air-to-liquid heat exchanger served to transfer heat from the circulating air to a flow of cooling water. By measuring the flow rate and temperature rise of the cooling water, the quantity of heat removed by the cooling system could be calculated. A comparison between this quantity and the electrical power input provided a measure of the over-all thermal efficiency. It was found that the cooling system removed 72 percent of the heat produced within the console.

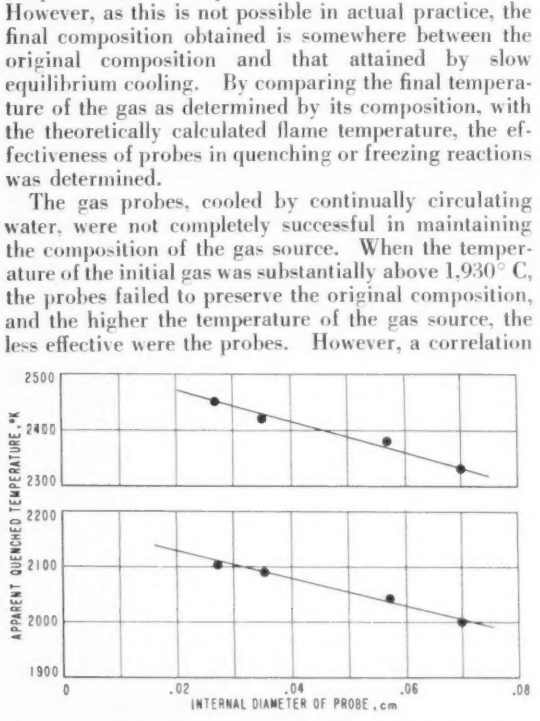
For further technical information, see Sequential flow cooling of electronic equipment, *P. Meissner, Elec. Mfg.* **58,** *No. 6, 120 (Dec. 1956).*

Water-Cooled Gas Sampling Probes *for jet-engine studies*

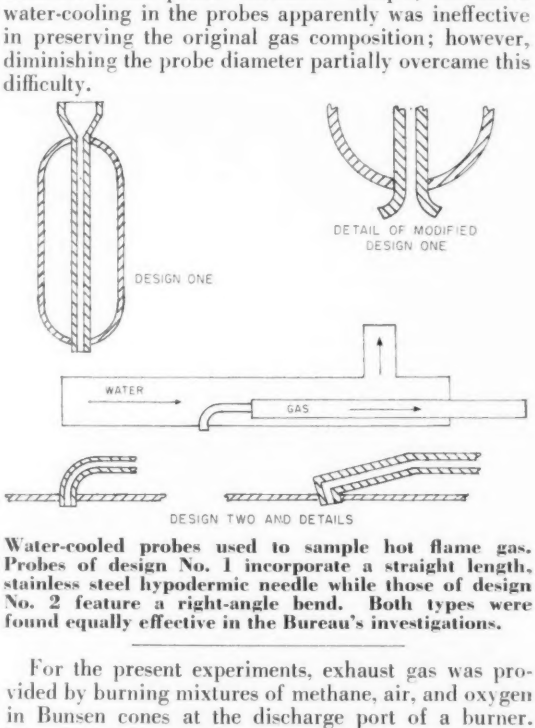
INTEREST in high-temperature combustion, especially as applied to the field of jet propulsion, has created a need for determining the nature and state of combustion gases in or near the region of chemical reaction. If the primary components of the exhaust gas could be retained unchanged, the temperature, fuel-to-air ratio, and combustion efficiency within a jet engine or rocket could be determined from analysis of a gas sample. As part of a program of combustion research, C. Halpern and F. W. Ruegg recently completed a study of the effectiveness of water-cooled probes in preserving the composition of gas samples drawn from hot exhaust gas.[1] The results of the investigation, which was sponsored by the Department of the Navy, indicate that temperature of the gas source and size of the probe affect the sample composition while materials of construction and configuration have little effect.

As the temperature of a gas sample in chemical equilibrium is gradually lowered, the composition of the gas changes until the sample reaches a temperature at which the reaction rates are too slow for further noticeable modification. Theoretically, if the sample were cooled instantaneously in the probe to this lower temperature, the composition would remain constant. However, as this is not possible in actual practice, the final composition obtained is somewhere between the original composition and that attained by slow equilibrium cooling. By comparing the final temperature of the gas as determined by its composition, with the theoretically calculated flame temperature, the effectiveness of probes in quenching or freezing reactions was determined.

The gas probes, cooled by continually circulating water, were not completely successful in maintaining the composition of the gas source. When the temperature of the initial gas was substantially above 1,930° C, the probes failed to preserve the original composition, and the higher the temperature of the gas source, the less effective were the probes. However, a correlation between the probe size and sample composition was found. Over the range of probe sizes between 0.027 and 0.07 cm, the temperature of the sample (as determined by its composition) decreased linearly as the diameter of the probe increased. Simple, convective water-cooling in the probes apparently was ineffective in preserving the original gas composition; however, diminishing the probe diameter partially overcame this difficulty.



Relationship between apparent quenched temperature and size of probe. The apparent quenched temperature, which is the temperature associated with the final composition, decreased linearly as the diameter of the probe increased. Hence the smaller the probe diameter, the less the composition is altered and the more effective the quenching.



Water-cooled probes used to sample hot flame gas. Probes of design No. 1 incorporate a straight length, stainless steel hypodermic needle while those of design No. 2 feature a right-angle bend. Both types were found equally effective in the Bureau's investigations.

For the present experiments, exhaust gas was provided by burning mixtures of methane, air, and oxygen in Bunsen cones at the discharge port of a burner. The rates of flow of both intake and exhaust gases were controlled in separate metering systems. A combustion train was used to analyze the gases.

One type of probe used was constructed of a hypodermic needle of stainless steel or tubing of other metals (as silver or platinum) mounted transversely in a piece of flattened copper tubing. Another design employed a hypodermic needle with a right-angle bend encased in thin-walled copper tubing. The bend was set as close as possible to the wall and the projecting tip was made less than one diameter of the gas passage in length. Performance of both types of probes was essentially the same.

During the testing, the different metals used in the probes often corroded or scaled. Steel probes were satisfactory, if interaction between the needles and copper body was prevented by heat-resistant paint. Accumulation of loose black scales of silver oxide in the gas passage of the silver probes made this material less desirable while platinum ones were satisfactory throughout. However, the probe material had little effect on the actual composition of the sample.

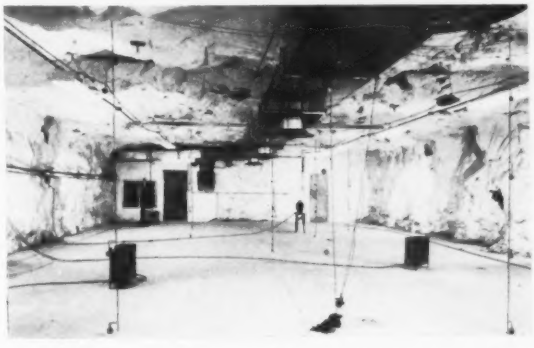
[1] *For further technical information, see* A study of sampling of flame gases, *by C. Halpern and F. W. Ruegg, J. Research NBS* **60**, 29 (1958) RP2818.

Heat Transfer in Underground Chambers

SINCE WORLD WAR II, much attention has been given to the use of natural or manmade caves by military, industrial, and civil defense groups for storage of goods or for shelter of personnel. One of the problems encountered is that of maintaining the space at a selected design temperature that may differ from that of the surrounding rock. When such an underground space is to be cooled or warmed to other than its natural temperature, heat transfer between the space and the earth must be considered under the transient conditions which exist. Heretofore, adequate data on the heat flow have not been available. To establish design criteria, scientists at the Bureau have undertaken both theoretical and experimental approaches toward providing the needed information. The studies were carried out for the Office of the Chief of Engineers, U. S. Army, by B. A. Peavy of the Bureau's heat transfer laboratory.

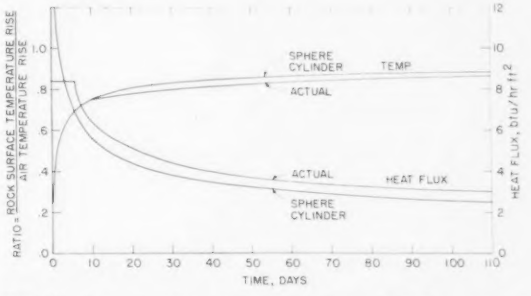
An analysis of heat transfer in underground chambers has recently been completed. The results provide a quantitative basis for predicting mathematically how much heating or air-conditioning a particular chamber will require to maintain a constant temperature. Subsequent experiments in an actual cave confirmed the range of accuracy of the mathematical solutions and supplied correction factors for representative chamber shapes.

The shapes of underground chambers approach those of hollow rectangular parallelepipeds. However, a mathematical solution for transient heat flow outward from a rectangular parallelepiped would yield expressions in three dimensions from which it would be troublesome to obtain numerical values. An infinite cylinder, or a sphere, may also be used to approximate the shape of a chamber, but the mathematical solutions obtained for these shapes are much more readily evaluated. The radius of an equivalent cylinder or sphere can be easily computed from the surface area of the chamber for which it is an approximation. Some departure of results calculated for these simple shapes from those of an actual chamber must be expected as a result of end, edge, and corner effects. Accordingly, experimental results were obtained in an actual cave to provide data for correction factors to make the mathematical solutions applicable to actual chambers with adequate accuracy.



Underground chamber used in experiments on heat transfer from manmade caves to the surrounding earth. Heat was supplied through the ventilating system and from space heaters on the floor. To measure temperatures at various points, thermocouples were suspended in the air, attached to the walls, ceiling, and floor, and placed at intervals up to 12 ft in depth in the rock surrounding the chamber.

For the experimental work, a chamber, 100 ft by 35 ft by 10 ft high, was chosen. It was located a few hundred feet underground and remote from the surface in a horizontal direction. The thermal properties of the dense rock surrounding the chamber were determined at the Bureau. Within the chamber, 385 thermocouples were installed at various locations in the air, on the rock surface, and at various distances in the rock to a depth of 12 ft. Heat was added to the air by electric strip heaters mounted in the air ducts. The heat input rate was measured with watthour meters connected to the heaters.



Graphical comparison of actual heat transfer over a period of time compared with results predicted from theoretical analysis.

Initially the measured rock temperature was nearly uniform at 53.8° F. After a constant heat input of 8.4 Btu/hr for each square foot of projected area of rock surface had been applied to the chamber for 139 hr, the temperature of the air reached 75° F. At this time, a thermostat began regulating the heat input to maintain the temperature at 75° F, and heat input was measured continuously for about 110 days, until sufficient data were taken.

The results of this and two similar experiments showed that the heat input necessary to maintain a constant temperature was slightly greater than that indicated by the mathematical solutions for the cylinder or the sphere. Correction factors based on the dimensions of the chamber were therefore formulated so that the mathematical solutions could be applied in a practical manner to caves of various shapes and dimensions. Numerical values of four mathematical functions needed for calculating the transient heat flow for the infinite cylinder and the sphere have been tabulated for a wide range of values of the independent variable. The independent variable contains time and size of chamber collectively.

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